Investigation of the potential disturbance of harbor seals by cruise ships in Disenchantment Bay, Alaska, May to August 2002

Draft Report No. 1: field activities and preliminary results

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Submitted by:

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ABSTRACT

Cruise tourism in Alaska has been growing rapidly since the early 1970's and there is increasing interest in evaluating possible impacts on sensitive coastal ecosystems. Recent attention has focused on the possible effects of tour vessels, including cruise ships, on subsistence resources that have been critically important to Alaska Natives for many generations. Harbor seals that haul out year-round on floating ice in tidewater glacial fjords are one such resource of concern because their pristine habitat is a popular destination for tourism. This study examined the potential effects of cruise ships entering Disenchantment Bay, Alaska on the behavior, abundance, and distribution of harbor seals from early May, at the onset of seal pupping, to early August, just prior to molting season. Analyses presented here of the behavioral observations (conducted from cruise ships) were confined to the single response of seals entering the water during a vessel approach; less overt behavioral responses were recorded and will be explored in subsequent analyses. The present analyses indicate that the likelihood of harbor seals vacating ice floes rose steeply when ships approached to less than 500 m; seals approached by a ship at 100 m were 25 times more likely to enter the water than seals approached at 500 m. Seals were also four times more prone to enter the water when ships approached them directly, rather than passing abeam. The proportion of seals that entered the water when ships passed within 200 m was nearly 75% compared to less than 10% entering the water at distances (i.e., > 600 m) where seals showed no apparent overt response to vessels. The sharp increase in seals entering the water at close distances – and the leveling off such response at greater distances – suggests that observers were able to view animals beyond the point where the seals were reacting overtly to vessels. Analyses of aerial survey data are underway and are expected to shed light on broader questions of whether or not there are detectable shifts in seal haulout frequency and the distribution of the seal population utilizing Disenchantment Bay. Although the preliminary results contained in this draft report are subject to revision or refinement based on subsequent analysis, the authors believe it is unlikely that the general conclusions presented here will change significantly.

INTRODUCTION

Alaska is a major destination in cruise tourism, with the third highest share (8%) of the total world capacity ranking only behind the Caribbean (50%) and the Mediterranean (10%; CLIA, 2002). The cruise ship capacity allotted to Alaska has nearly tripled since 1987, surpassing the Bahamas (5%), and current annual growth is 8% compared to the 7% industry average. The North American fleet comprises 167 ships with an additional 42 projected by 2006 (CLIA, 2002). These statistics combined with a growing interest globally in nature-based and cultural tourism, eco-tourism, and adventure travel (Reynolds and Braithwaite 2001; WTO 2001), point to Alaska's growing popularity among cruise tourists. This growth has prompted concern about the potential environmental impacts of cruise tourism in Alaska and whether it is environmentally sustainable. In particular, marine living resources and the local people who rely on them may be sensitive to the changes brought about by the presence of cruise ships. Marine mammals are some of the most conspicuous examples of potentially vulnerable species because they historically congregate in coastal habitats, such as tidewater glacial fjords, that are now popular destinations for cruise tourists because of their pristine nature.

Harbor seals (*Phoca vitulina richardii*) in Alaska inhabit coastal and estaurine waters from Southeast through the Gulf of Alaska to Cape Newenham in the Bering Sea. They haul out, rear pups, and molt on rocky outcrops, sandy beaches, and ice floes. Following declines in populations in the Gulf of Alaska (Pitcher 1990; Frost et al. 1999; Jemison and Pendleton 2001; Small et al. 2001) it has become increasingly important to understand the factors that affect seal survival and recruitment. Ice floes emanating from tidewater glaciers serve as important pupping grounds for harbor seals from mid-May to at least early July, and as molting platforms during August (Streveler1979; Hoover 1983). Whereas the largest terrestrial haulout sites number several hundreds of animals, such glacial sites have ice fields that are used by thousands of seals (Withrow et al. 1997; 1998; 1999a; 1999b; 2001). These seal aggregations have nutritional and cultural importance for Alaska Natives, such as those living in the Yakutat area, who have utilized sealing camps in Yakutat and Disenchantment Bays (Fig. 1) for many generations. Harbor seals were likely an important resource as far back (and prior) to the earliest known settlements of the Yakutat Forelands area – 1100 years ago (Davis 1996). Despite the importance of these seals, little is known of their trends in abundance or why the animals concentrate in the ice fields in such large numbers throughout the year. Glacial ice habitat may function uniquely as a refuge from both land and marine predators and by providing platforms for resting and rearing young.

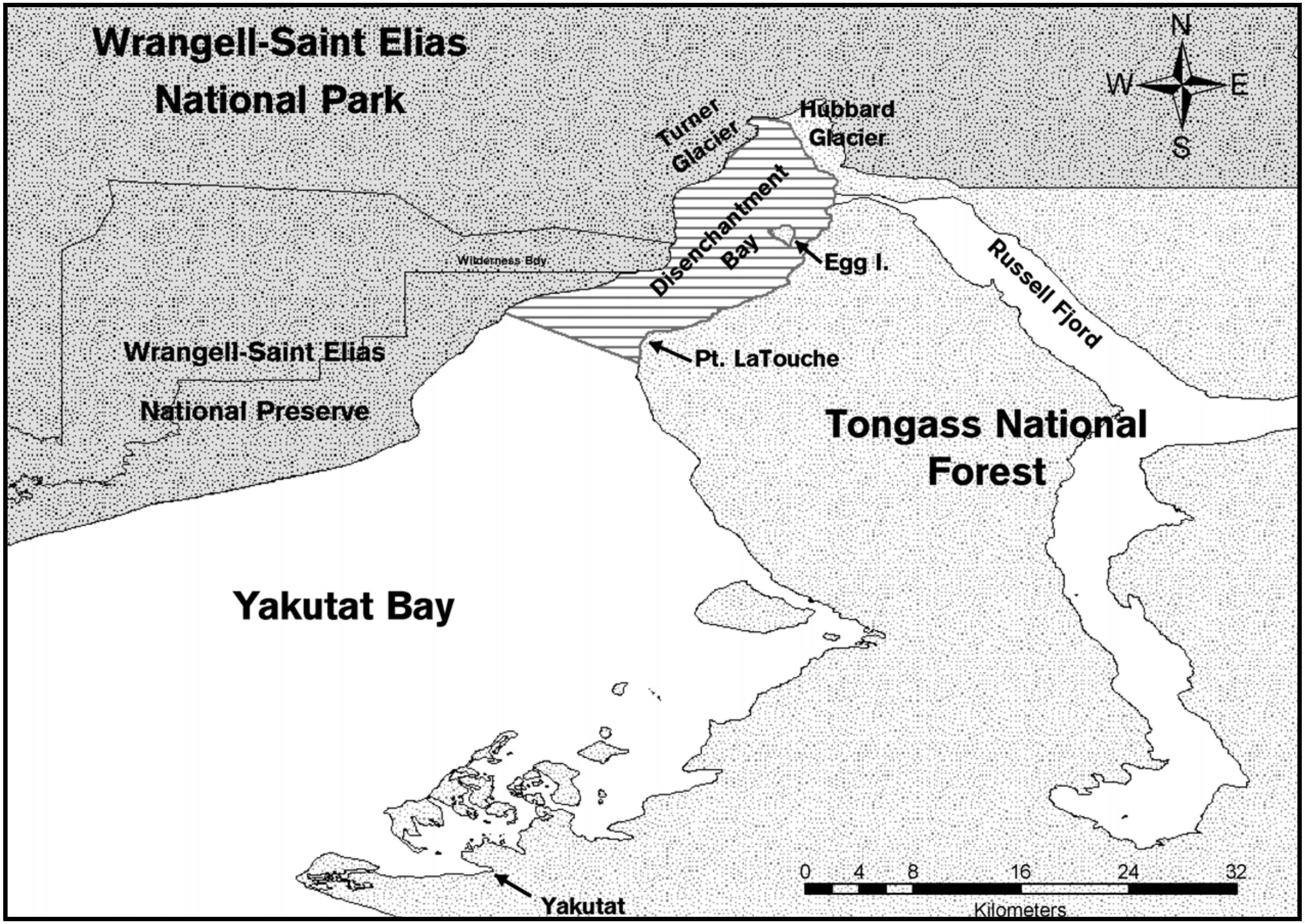

Figure 1. The study area for examining potential disturbance of harbor seals (*Phoca vitulina richardii*) by cruise ships. The Disenchantment Bay study area is defined roughly by the hatched area. Harbor seals occurred in highest concentrations in the northwestern and northernmost portions of the bay.

Tour vessels were first reported in Disenchantment Bay in 1883, though the number of visits probably remained low during most of the twentieth century (USFS 2001). More than a century later, in 1989, still fewer than 15 visits occurred per year (Kozie et al. 1996). In 2002, 168 visits by cruise ships were scheduled, a 7% increase from 2001. This amounts to near daily visits from mid-May to September. Cruise ships typically venture at least as far north as Egg Island, ice conditions permitting, to afford passengers a closer view of Hubbard Glacier (Fig. 1). As many as five ships, which can be nearly 1000 feet (305 m) long and 100 feet (30 m) wide, have visited the bay on peak traffic days. Disenchantment Bay may experience further increases in ship traffic due to three factors: expected increases in the cruise ship fleet, bans of some cruise lines from nearby Glacier Bay National Park, and potentially tighter restrictions on annual cruise ship visits in Glacier Bay (currently set at 139). Although the densest concentration of harbor seals in Disenchantment Bay appears to be outside the normal traffic corridor of vessels approaching the glacier, seals distributed on ice in the southern portions of the bay occur within the corridor frequently used by cruise ships. Females with pups may favor southern areas of the bay – as observed in May 2001 (J.K. Jansen, pers. obs.) – because of a general tendency for pregnant and post-partum females to haul out at the periphery of mixed groups or at separate nursery sites altogether (Jeffries 1982; Allen et al. 1988; Thompson 1989).

Alaska Natives from Yakutat (Yakutat Tlingit Tribe [YTT]) are concerned that the presence of cruise ships in Disenchantment Bay – which peak in numbers during seal pupping – are having adverse impacts on the distribution and abundance of harbor seals. The YTT believes that cruise ships may be disrupting the seals' normal behavior during pupping, which may lead to reduced survival of newborn pups and a subsequent population decline. Cultural traditions of the Tlingit Tribe have held that harbor seals should be left undisturbed during the period from mid-May through June because it is a critical time for pup rearing. Seal hunters from Yakutat believe that the availability of seals has declined over the past 10-15 years, as reflected by hunting trips that have progressively been less successful and have required more time. Hypothesized declines in seal numbers are consistent with trends in subsistence harvests by Yakutat hunters. Seal takes per capita in 2001 were only 38% of the 1993 levels, a steep decline (65%) from a peak in 1996 (Wolfe and Mishler 1993; 1996; 2001). Though there has also been a downward trend in harbor seal harvests for the entire Southeast Alaska region, the decline of Yakutat sealing was more than twice the regional average. Though harvest estimates do not take into account fluctuating levels of hunting effort, the number of households that use seal has remained consistently high, falling slightly from 93% in 1993 to 85% in 2001 (Wolfe and Mishler 1996; 2001). Harbor seals are a valued resource for the Tlingit Tribe, one that they perceive has become less available in Disenchantment Bay in recent years.

There are no published findings on how seals on glacial ice respond when they are approached by vessels, though studies have been undertaken. In Muir Inlet, Glacier Bay, a study in 1985 suggested that more harbor seals entered the water in response to smaller boats, such as kayaks, than to larger cruise ships, though the latter disturbed animals at greater distances (Calambokidis et al., unpub. ms.). In McBride Fjord, Glacier Bay, researchers found that seals entered the water more often and in larger numbers in response to kayaks than larger skiffs (Lewis and Mathews 2000). In Johns Hopkins Inlet, Glacier Bay, Mathews (1994) reported that harbor seals vacated ice floes at greater distances to cruise ships than much smaller boats (i.e., one-quarter the size). Similar results on harbor seals at terrestrial haulout sites support the hypothesis that vessel type may be as important as approach distance in determining the outcome of seal-vessel interactions (Suryan and Harvey 1999; Lelli and Harris 2001). The sensitivity of animals to such factors may also differ relative to experience and their breeding or molting status. Suryan and Harvey (1999) found increasing levels of tolerance among harbor seals to repeated disturbance by small boats, and increasing vigilance and disturbance with number of pups present across three sites. In Disenchantment Bay, potential sources of human disturbance to harbor seals are mainly the visitation of cruise ships, which occurs from mid-spring to late summer, and subsistence hunting, which occurs throughout the year though less so in late spring during pupping (Wolfe and Mishler 2001). Charter or private boats reportedly transit the ice field infrequently to view the Hubbard Glacier or to enter Russell Fjord.

The focus of this study was to document and assess the potential disturbance of harbor seals in Disenchantment Bay by cruise ships that move through and near areas of floating ice where seals are present. The two working hypotheses were: 1) individual seals hauled out on floating ice respond behaviorally to approaching vessels (i.e., by becoming agitated or entering the water); and 2) the population of seals in Disenchantment Bay responds to vessels through shifts in spatial distribution and/or by leaving the haul-out area. Of particular importance was evaluating the potential disturbance of nursing females, as they have shown to be particularly sensitive to disturbance at terrestrial sites (Newby 1973; Lawson and Renouf 1985; Suryan and Harvey 1999). To test these hypotheses, the potential response of animals to vessel traffic was assessed at three spatial and temporal scales: 1) fine scale – daily observations of individual seal behavior in relation to vessel approach distance, 2) medium scale – weekly aerial surveys of seal distribution and relative abundance in Disenchantment Bay, and 3) large scale – monthly aerial photographs of regional seal distribution and total abundance at glacial haulouts of the greater Yakutat area (i.e., Disenchantment and Icy Bays).

This first draft report summarizes the field activities in 2002 and preliminary findings for the seal behavior observations (i.e., fine scale methods) that were conducted from cruise ships. Subsequent draft reports, and ultimately the final report, will summarize all the findings relating to each of the three temporal and spatial scales examined. These reports will be made available as the respective analyses are completed. An overarching goal of this study is to produce reliable information on the behavior, distribution, and abundance of harbor seals in areas frequented by tour vessels to assist tribal representatives and the cruise ship industry in their mutual desire to maintain healthy populations of harbor seals in the ecosystems represented by tidewater glacial fjords. Although the preliminary results contained in this draft report are subject to revision or refinement based on subsequent analysis, the authors believe it is unlikely that the general conclusions presented here will change significantly.

METHODS

Study Area

Disenchantment Bay comprises approximately 80 sq km of non-uniformly distributed ice floes of varying size spreading south from the two tidewater glaciers, Hubbard and Turner. Ice coverage varied widely – from solidly packed areas with no open water visible, as in the northern area between the glaciers – to single floes surrounded by expanses of water. Disenchantment Bay is unusual in that the two glaciers that generate the floating ice are not at the terminus of the fjord (Fig. 1). Thus, both tidal currents and the wind cause the ice field on which seals haul out to constantly change and disperse in the bay. These conditions, however, may have changed during the latter part of this study. Tidal flow in and out of Russell Fjord was restricted and ultimately precluded from June to early August after Hubbard Glacier advanced rapidly and blocked off the inlet to the fjord. This effectively created a lake that persisted until the moraine dam was breached by the rising water on 14 August. Despite this anomaly, the densest concentration of seals was found – prior to and following the formation of the ice dam – in the northwest area of the bay (Fig. 1).

The study area was geographically defined as the region north of Pt. LaTouche, which essentially marks the boundary between Yakutat and Disenchantment Bays (Fig. 1). Though some ice floes were scattered to the south of this boundary, the patches of densest ice were nearly always north of this boundary, especially in the upper reaches of the bay where the vast majority of harbor seals were located. Higher concentrations of ice and seals were sometimes observed to the south, in Yakutat Bay, and thus shipboard observations sometimes occurred in these areas. The medium-scale aerial surveys were confined to Disenchantment Bay during May, but as ice increased through the season in northern areas of Yakutat Bay, observers began flying a single transect south of Pt. LaTouche in areas of dispersed ice. The large-scale aerial photography was confined to the area north of Pt. LaTouche; in Icy Bay, the photo surveys were conducted north of Kichyatt Point.

Whereas the general distribution of harbor seals in Disenchantment Bay is fairly well known, the numbers of seals using these areas is less clear. The area between the two glaciers is historically where Native hunters have observed the densest aggregations of seals, and also where seals were concentrated during surveys by the National Marine Mammal Lab (NMML) in 1997 and 2001. Past estimates of the number of seals using Disenchantment Bay, based on aerial surveys using rough visual or photographic methods, were prone to observer biases due to the difficulty of counting animals over large areas of scattered, moving ice with no topographical reference. Moreover, the seals that are visible on the ice during an overflight represent only a fraction of the total population since many remain in the water. Therefore, even the most accurate counts must be corrected upward by some factor that integrates the varying propensities of seals to haul out under varying environmental conditions. Kozie et al. (1996) derived uncorrected estimates for the pupping period (mid-May) in Disenchantment Bay of about 750 harbor seals. During the August molt, estimates range from 467 (Kozie et al. 1996) to 1009 seals (Withrow et al. 1997). Preliminary counts from August 2002 using more accurate techniques for counting (e.g., 100% coverage via high-altitude, high-resolution photographs) yielded uncorrected counts of at least 1738 seals (NMML, unpublished data). Still, it is unknown to what extent the population in Disenchantment Bay interacts with populations in the greater Yakutat Bay area or with those in adjacent bays along the outer coast (e.g., Icy and Dry Bays). Radio-tagged seals using floes in Tracy Arm, near Sawyer Glacier in Southeast Alaska, spent more than half of their time in areas outside the fjord (100 km by water), especially by the onset of pupping at which time all tagged seals were outside the fjord; the two-thirds that returned (6 of 9) stayed only for brief visits (Jansen et al. 2001).

Fine Scale Sampling

Shipboard observations were conducted from 14 May 2002, when the first cruise ship entered Disenchantment Bay, to 1 August 2002 (Fig. 2), by which time all pups had likely been weaned. To ensure full coverage of vessels when ships were first entering the bay, arrangements were made to transport observers to all ships in May including those that did not embark pilots or cultural interpreters

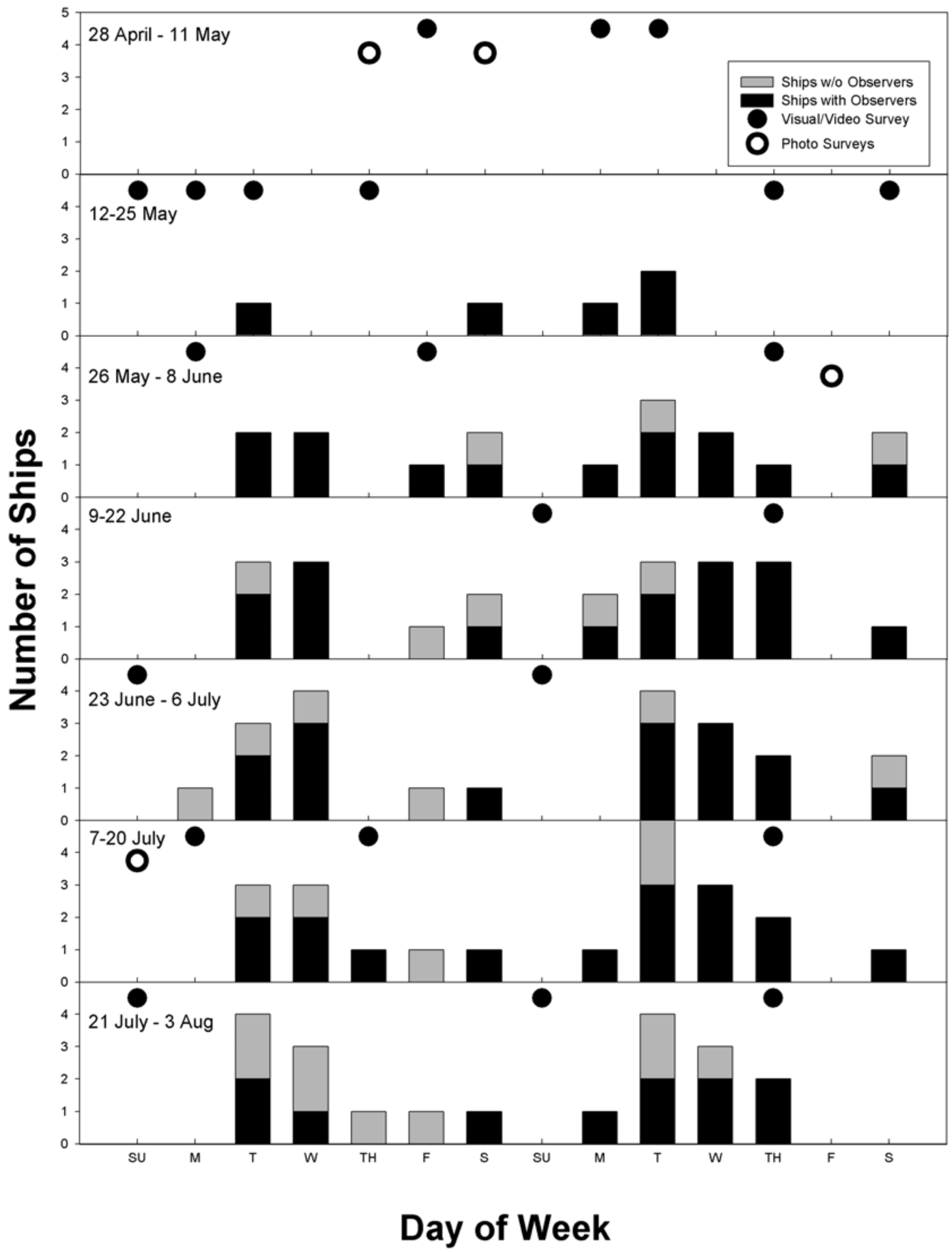

Figure 2. Distribution of cruise ship visits to Disenchantment Bay, with and without observers, and aerial survey samples, 28 April to 3 August 2002. Additional surveys were flown on 4 August (visual/video) and 14-15 August (photo). Photo surveys of Icy Bay were flown on the same day as Disenchantment Bay except for those flown on 4 May and 15 August.

from Yakutat (e.g., Holland America Lines). From June to August, when there were more ships than observers on a particular day, higher priority was given to earlier ships provided the tender boat was scheduled. Portable GPS receivers were used to continually log the positions of ships during the observers' visits. Observers were typically onboard for 5-6 hours, which included at least two hours of transit to and from the ice field.

Observations were made of seals hauled out on ice during the entire period a ship was within viewing range of animals, which was typically out to maximum of 800-1000 m, depending on visibility. There were four possible observation posts onboard, each being described as some combination of port or starboard, and bow or stern. As many as three posts were occupied on a single cruise depending on the number of observers present. Observers noted whether ships were inbound toward Hubbard Glacier, rotating in place, or outbound toward Yakutat Bay. Efforts were made to first locate individual seals and groups at varying distances and bearings from the ship to provide a behavioral contrast between near and distant animals. A seal group was defined as one or more animals hauled out on a single ice floe. Once chosen for observation, a seal group was observed continuously until the seals either passed abeam of the ship (for groups observed from the bow), entered the water, or passed out of observation range astern (for groups observed from the stern). Distances between ships and seals were estimated using laser rangefinder binoculars (Leica Vector™, Ashbury International Group, Inc., Sterling, VA) or an inclinometer.

The behavioral state of seals was recorded as: 1) resting - seal was motionless with head down, 2) alert - seal was stationary but had head up, 3) active - seal moved across the ice floe or interacted with neighbors, or 4) entered water - seal departed ice floe during observation period. Behavioral observations were recorded during 15-sec intervals on data forms or by using a hands-free digital voice recorder. The time that a digital voice recorder was started was noted and recorders ran continuously during observations. Digital voice files were later downloaded, played back via sound editing software that allowed observers to assign times to their observations, and transcribed into a database. For each 15-sec sample, observers recorded the distance and bearing (relative to the ship in 15° increments) to the group, total number of animals in a group, and the number of animals that exhibited each level of excitement during the interval. Only the highest level of excitement was recorded for each seal (e.g., "enter water" was the highest excitement, "resting" was the lowest). Data on mothers and pups were recorded separately from other animals and independent of each other. For each group observed, additional data were collected on covariates such as ice coverage (estimated in 10ths within a 50 m radius of the seal group), ice floe size (longest axis), and other potential sources of disturbance to the seals. Weather conditions were noted at the beginning of observations and whenever significant changes occurred thereafter. Appendix 1 shows the sampling guidelines observers followed; Appendices 2 and 3 illustrate the data forms used on the cruise ships. As a separate protocol, observers were sometimes stationed amidships to estimate distances to and size of seal groups abeam of the ship. These data will be used to calculate seal densities as a function of distance from the ship.

In total, observers recorded data on 76 of the 104 cruises (73%) that were scheduled to visit Disenchantment Bay during the study (Fig. 2). Navigational tracks were acquired from GPS units on all but three of these cruises; there were two GPS malfunctions and one GPS unit was stolen. We still anticipate acquiring from the North West CruiseShip Association (NWCA), as arranged, the navigational tracks of ships from which data were not collected. A total of 772 seal groups were observed comprising 6008 15-sec observations and a total effort of about 207 observer-hours. Observations were taken amidships on 52 cruises and distances were estimated to a total of 1796 seal groups.

Analyses of shipboard observations

The preliminary analyses presented in this report were based only on data collected during 15-second observation periods while the ships were moving (as opposed to stopped or rotating in place). The data were further focused by considering only the forward-looking (bow) observer positions and by eliminating a few observations for which distance or bearing was not recorded. These criteria produced a data set from 584 seals observed in 307 groups.

Of the four behavioral responses recorded, entering the water was likely to have a stronger relationship to any potential longer-term impacts on the seals' vital rates than the other responses (resting, alert, or active). Also, analysis of the water entry response was simpler because it involved just one transition, from on ice to in the water, whereas the other responses could include reverse transitions and transitions between multiple behavioral states (e.g., a sequence recorded as resting, alert, resting, active, alert, on consecutive 15-sec observation intervals). Therefore, we have focused in the present report on entering the water as the response variable. This choice allowed assignment of unique identifiers to all seals in the data set, even though the data had been recorded simply as counts of the numbers of seals within each group displaying the four behavioral responses. The seals were given individual identifiers by numbering the individuals within a group; the first to enter the water was numbered "1", the second numbered "2", and so on. Remaining seals, that did not enter the water while under observation, could be numbered arbitrarily because they all had identical behavior records (when considering only the water entry response). Representing the data in this way, there were 5,344 records

(15-second observations) from the 584 seals. Each record included the seal and group identifiers, the start and stop times of the 15-second interval, the response (0 if the seal stayed on the ice, 1 if the seal entered the water), and the explanatory variables ("covariates"): distance from the ship to the seal, bearing from the ship to the seal, seal group size, and type of seal (mother, pup, or other).

The data we described above are "time to event" data with censoring. The censoring occurred whenever a seal was lost to observation before entering the water, which occurred, for example, when the seal passed abeam of the ship or when the shipped stopped its forward progress while a seal was being observed. For censored time to event data, the Cox proportional hazards model is a natural and widely used technique for estimating the effects of covariates on a response variable (Therneau and Grambsch 2000). In such analyses, the response is often death of the subject under observation, which is why this type of analysis is commonly called "survival analysis", but the technique is equally applicable to other types of binary censored outcomes, such as a seal entering the water. Although the basic Cox model assumes linear relationships and time-constant covariates, we used semi-parametric extensions of the Cox model that allowed the data to suggest the functional form of the covariate effects and that allowed for time-dependent covariates such as distance from the seal to the approaching vessel (Therneau and Grambsch 2000). We used S-Plus® version 6.1 for Windows (Insightful Corp., Seattle, WA) for all Cox regression modeling.

The Cox model is ideal for expressing covariate effects in terms of relative risk. For example, a subject with a value of 10 units for covariate A might be found to have twice the risk of the response outcome as a subject with 15 units of A. However, the absolute risk (e.g., What is the risk that a subject with 10 units of A will experience the outcome?), is not a product of the Cox model. For this initial analysis, we computed simple proportions of seals under observation entering the water for each of several distance bins as an approximate measure of the absolute risk.

Medium and Large Scale Sampling

Aerial surveys of relative seal abundance and distribution were conducted about 3-4 times weekly from 2 - 25 May, 12 days prior to and after the first entry of cruise ships into the bay. Surveys were conducted daily from 12-16 May (except 15 May) to gather additional samples immediately preceding and following the first cruise ship visit of the year (14 May). Subsequent surveys were conducted twice weekly, weather permitting, starting 27 May and ending on 4 August, after the completion of pup rearing. These surveys were timed to facilitate a comparison of seal abundance and distribution between periods of low and high ship visitation. Thus, the first survey in the week was attempted on Sunday or Monday, which followed a period of reduced ship visitation, and the second on Thursday or Friday which followed a period of increased visitation (Fig. 2). Surveys were flown between 13:00 - 15:00 h (local time) to coincide with the daily peak in numbers of seals hauling out (Hoover 1983; Calambodkidis et al. 1987; Jansen et al. 2001). A single engine aircraft (Cessna 206; Yakutat Coastal Airways Inc., Yakutat, AK) was flown at a target speed of 90-100 knots and altitude of 305 m (1000 ft). Two survey methods were employed simultaneously during overflights of the haulout areas: observer line-transect and video strip-transect. A standard grid of 14 transects, oriented along the longest axis of the bay and separated by 400 m, was flown over Disenchantment Bay (Fig. 3); a fifteenth transect was added in June to quantify the distribution of animals in southern Disenchantment Bay and northern Yakutat Bay as seals were sometimes observed there in low densities.

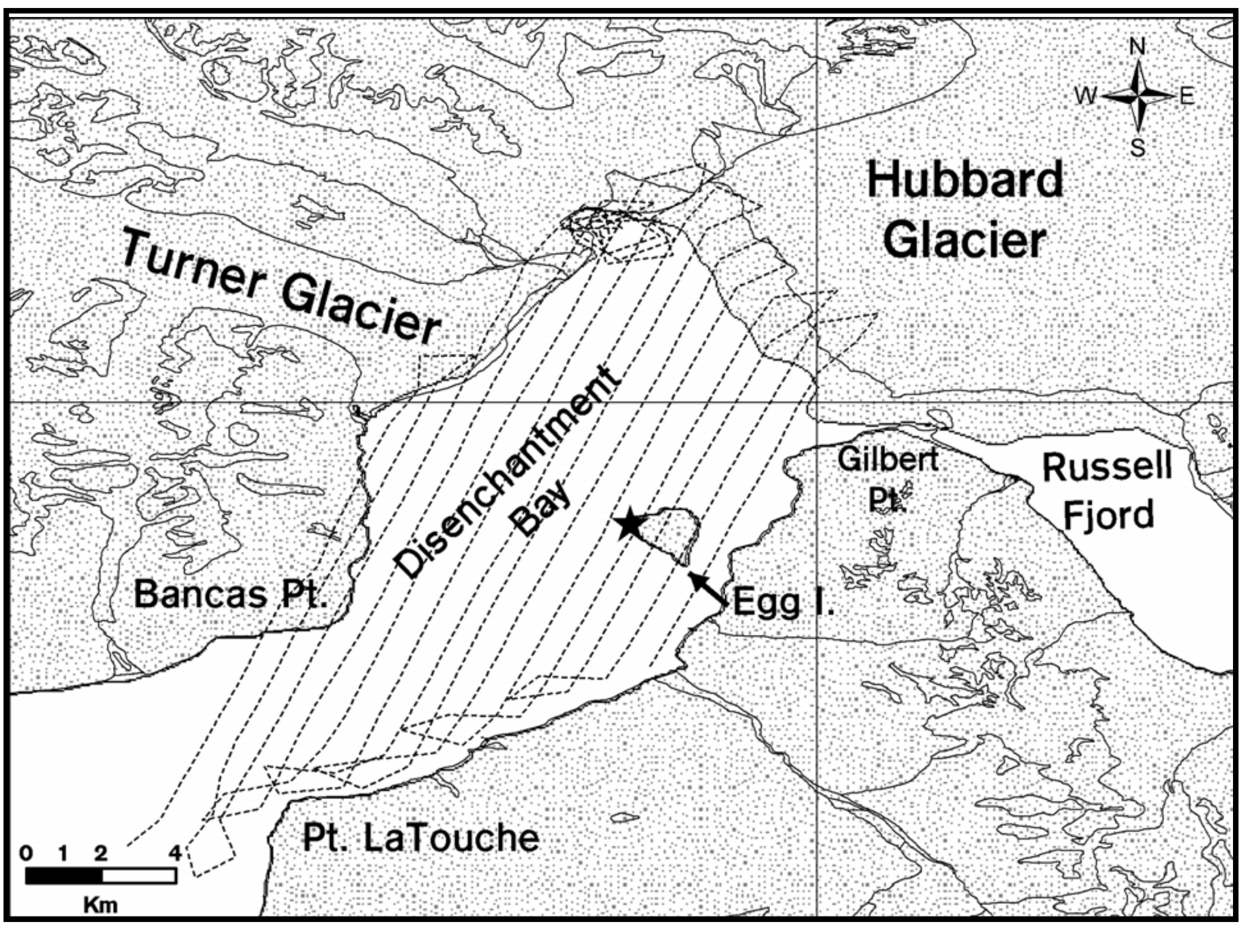

Figure 3. Map of Disenchanment Bay study area. A typical aerial transect grid for the video and visual surveys is shown by the dashed line. The location of the weather station is shown with a star. The location of the face of Hubbard Glacier was mapped in early June 2002 (D. Seagars,USFWS)

For the observer line-transect method, two 50-meter strips to the side of the plane were delineated using a plexiglass sighting board attached to the aircraft's window (Fig. 4). Eye position relative to the marks was fixed by aligning visually a pair of marks on the sighting board like a gunsight. The sighting board allowed quick measurement of distance intervals so the observer could remain focused on the ice to avoid missing seals. Normally, seals were counted within both of the two 50-meter strips; however, when high seal density made accurate counting difficult, the observer focused attention just within the nearest strip. Effort data, time, and geographic position were recorded throughout the survey via a portable GPS unit. Environmental data – such as ice conditions, visibility, and weather – were also recorded by the observer. The single observer surveyed out the port side of the aircraft, recording seal counts, presence of vessels, and conditions in real time on the audio track of the video tape.

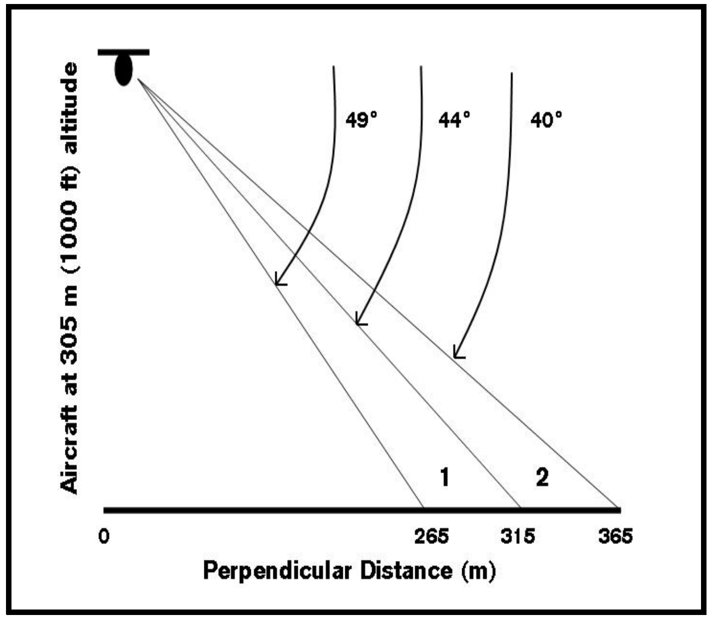

Figure 4. Vertical angle measurements of perpendicular distance of the two sighting bins from the survey aircraft.

For the video survey, a video camera was mounted vertically on the starboard wing strut with the zoom lens preset to record a 70-meter strip directly beneath the plane. Time and GPS coordinates were initially imprinted on the tape as an aid in mapping seal and ice distribution during the analysis phase. In June, we discontinued imprinting to optimize the viewing area during playback analysis, then matching the local time of seal sightings (visible in a smaller area on the screen) with locational fixes from the GPS unit using its associated local times. The medium-scale aerial surveys were flown on 23 days comprising nearly 40 hours of observations and 60 hours of time in flight.

Video tapes were played back and analyzed on a 13-inch video monitor (Sony Trinitron, model PVM1344Q) by a single observer, the same person (S. Dahle) throughout the analysis. Harbor seals hauled out on ice were counted as they passed an arbitrary horizontal line drawn across the middle of the screen. This ensured that the virtual width of the survey strip was kept constant even though the plane (and the camera) may have rocked side to side and thus recorded, if only briefly, seals that were just outside the strip. This method also standardized the position on the screen, and thus the survey time, at which seals were sighted. Observations were communicated to a separate recorder who entered the number of seals on individual ice floes and the local time (which was related to geographical position), as well as a qualitative estimate of ice coverage within the frame containing the seal(s) – to the nearest tenth for ice $3 m, longest axis. In addition, ice coverage was estimated at 15-sec intervals when seals were not sighted which, depending on the speed of the plane, provided a minimum of 0.75 - 1 km × 400 m resolution of ice conditions.

Disenchantment and Icy Bays were surveyed using large format (9 in × 9 in) vertical photography four times at approximate monthly intervals during the study (Fig. 2). The photogrammetric surveys (AeroMap, Inc., Anchorage, AK) were designed to provide complete coverage of the ice-filled regions of each bay, with 20% endlap and 40% sidelap between neighboring photographs. The surveys were flown at 3000 ft, providing photographs at 1:6000 scale. A total of eight large-scale photographic surveys producing 1267 images was flown: Disenchantment Bay (2 May, 7 June, 7 July, 14 Aug), and Icy Bay (4 May, 7 June, 7 July, 15 Aug).

Meteorological sampling

Meteorological conditions in Disenchantment Bay were recorded via a remote weather station (HOBO ®, Onset Computers, Bourne, MA) deployed on Egg Is. (Fig. 3) from 1 May to 2 August 2002. It collected data on temperature, wind speed, relative humidity, precipitation, and barometric pressure. With the exception of a power failure for a short period mid-season, the data are complete and will assist in analyses that require weather covariates.

RESULTS

Fine Scale - shipboard observations

A Cox regression indicated that neither group size nor seal type was significantly related to the risk of seals entering the water ($P > 0.3$). Distance and bearing from the vessel, however, were highly significant explanatory variables for that risk. Figure 5 shows the functional form of the relationship with varying approach distance, obtained using a penalized smoothing spline (Therneau and Grambsch 2000). The Cox regression results are in terms of relative risk; to interpret Fig. 5, it is easiest to compare two points. For example, at a distance of about 500 m, the effect curve begins to rise steeply. Because the vertical axis is on a natural-log scale, this point corresponds to a risk of $e^{0.5} = 1.6$. Comparing this to the scenario at very small distances, say less than 100 m, where the curve has a value of about 3.7, indicates that a seal approached at less than 100 m is about $e^{3.7}/e^{0.5} = 25$ times more likely

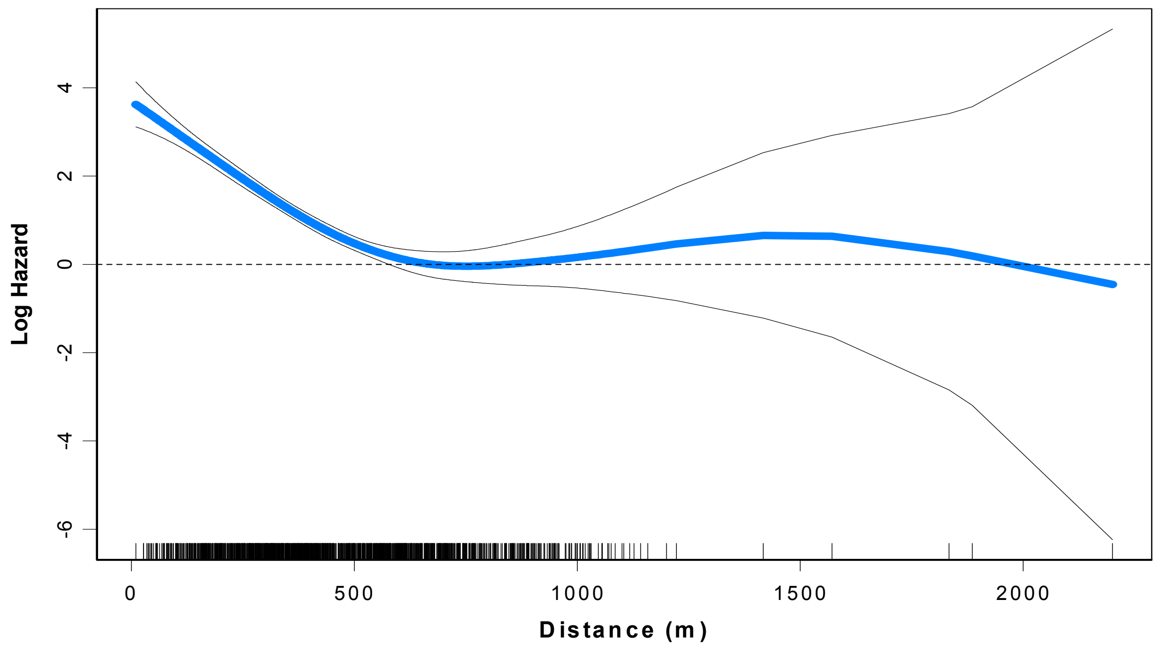

Figure 5. Relative risk, expressed as the logarithm of the hazard, of a harbor seal entering the water (abandoning its glacial ice haul-out platform) in response to varying distances of approach by cruise vessels in Disenchantment Bay, Alaska. Approximate 95% confidence limits are shown by the thin curves. The observation distances are marked by the "rug" fibers plotted at the bottom.

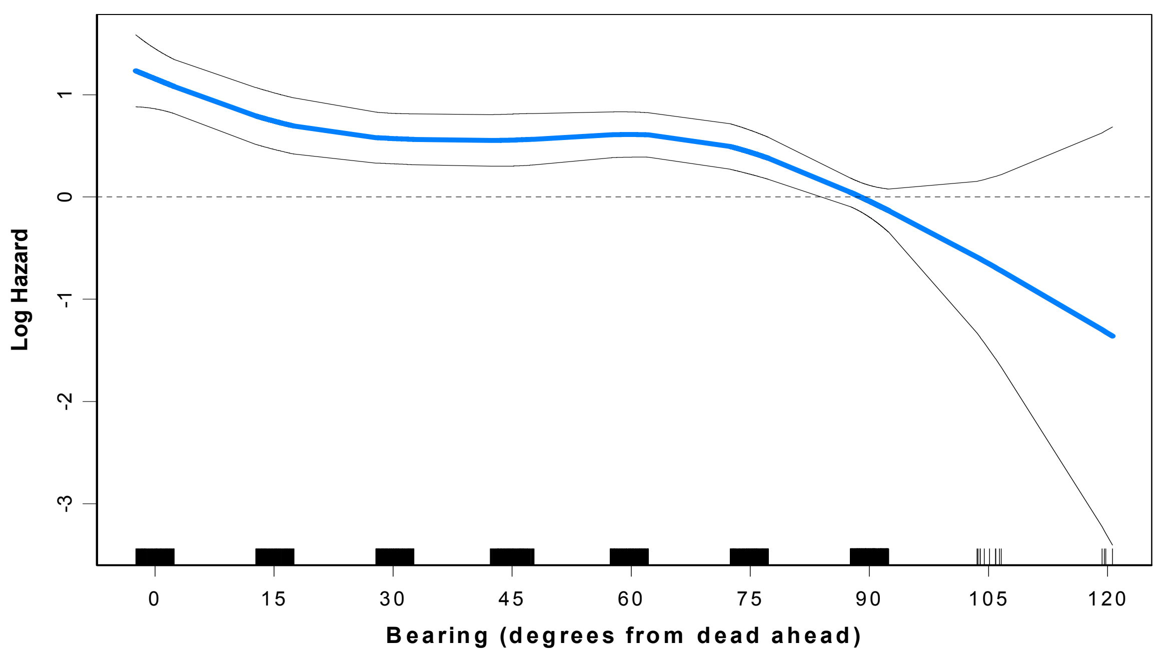

Figure 6. Relative risk, expressed as the logarithm of the hazard, of a harbor seal entering the water (abandoning its glacial ice haul-out platform) in response to varying bearing angles during approach by cruise vessels in Disenchantment Bay, Alaska. Approximate 95% confidence limits are shown by the thin curves. The observation bearings are marked by the "rug" fibers plotted at the bottom, which were jittered to better illustrate the relative sampling densities at the 15 degree measurement increments.

to enter the water than a seal approached at 500 m. Beyond about 600 m, there appeared to be very little effect of the ship's approach, though the confidence intervals expanded rapidly because of the relatively small number of observations at large distances.

Figure 6 shows the effect of variations in bearing angle on the risk of seals entering the water. Relative to a base risk of $e^0 = 1$ when a seal was directly abeam of the observer (90 degrees), the risk of a seal entering the water when approached dead ahead of the vessel was about $e^{1.3} = 3.7$ times greater. The risk appeared to be considerably lower for seals observed aft of the observer's position on the bow, but again the confidence intervals increased rapidly because of small sample size.

Because of the potential for interactions between distance and bearing angle (i.e., the response to distance may vary with the bearing), we investigated the shape of the response surface over the two variables simultaneously. This was not possible to do within the Cox regression framework alone. Instead, we fit a Cox regression with no explanatory variables and then used a generalized additive regression (Hastie and Tibshirani 1990) to explore the relationship between distance, bearing angle, and the residuals from the Cox regression (Fig. 7). For any fixed value for distance, there appeared to be a slight trend toward increasing risk of water entry as the bearing angle decreased from 90 degrees (abeam) to 0 (ahead). This indicated that seals responded to the approach of the ship, rather than how visible it was, e.g., a ship viewed from directly in front would appear smaller (and be less visible) than one viewed from abeam. That is, seals entered the water at shorter distances when ships were bearing down even though the ships appeared smaller.

Figure 8 shows estimates of the proportions of seals that entered the water, in 10 distance bins of 100 m width. These estimates were derived from the 526 seals (279 groups) that either entered the water during observation or passed abeam of the ship while still on the ice; seals that were lost to observation for other reasons (e.g., ship stopped moving) were not included. Each proportion was calculated as the simple ratio of the number of seals that entered the water at distances that fell within the 100 m-wide bin, divided by the total number of seals that were observed at distances within the bin. These values provide a means of translating the purely relative (i.e., without units) values of the Cox regression into an absolute measure of the risk of water entry as a function of approach distance. Still, we emphasize that these measures are only approximations because they do not account explicitly for the censored nature of the proportion data (i.e., the seals that passed abeam of the ship and those that were lost to observation do not contribute to the measure), they do not adjust for the simultaneous effect of bearing angle, and they do not account for the amount of time the seals were "exposed" to the ship in each distance bin. Despite this approximation, the estimates in Fig. 8 were qualitatively similar to

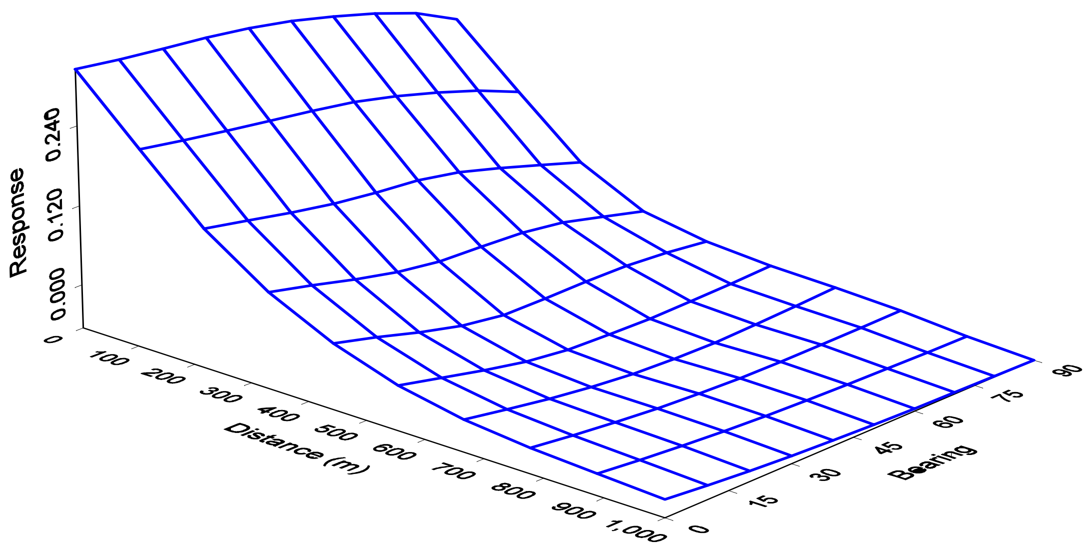

Figure 7. A response surface showing the interaction between approach distance and bearing to the vessel as covariates explaining the risk of a harbor seal being disturbed from its ice haul-out platform in Disenchantment Bay, Alaska. The units of the response are arbitrary because the surface was obtained by generalized additive model regression of the residuals from a null Cox model.

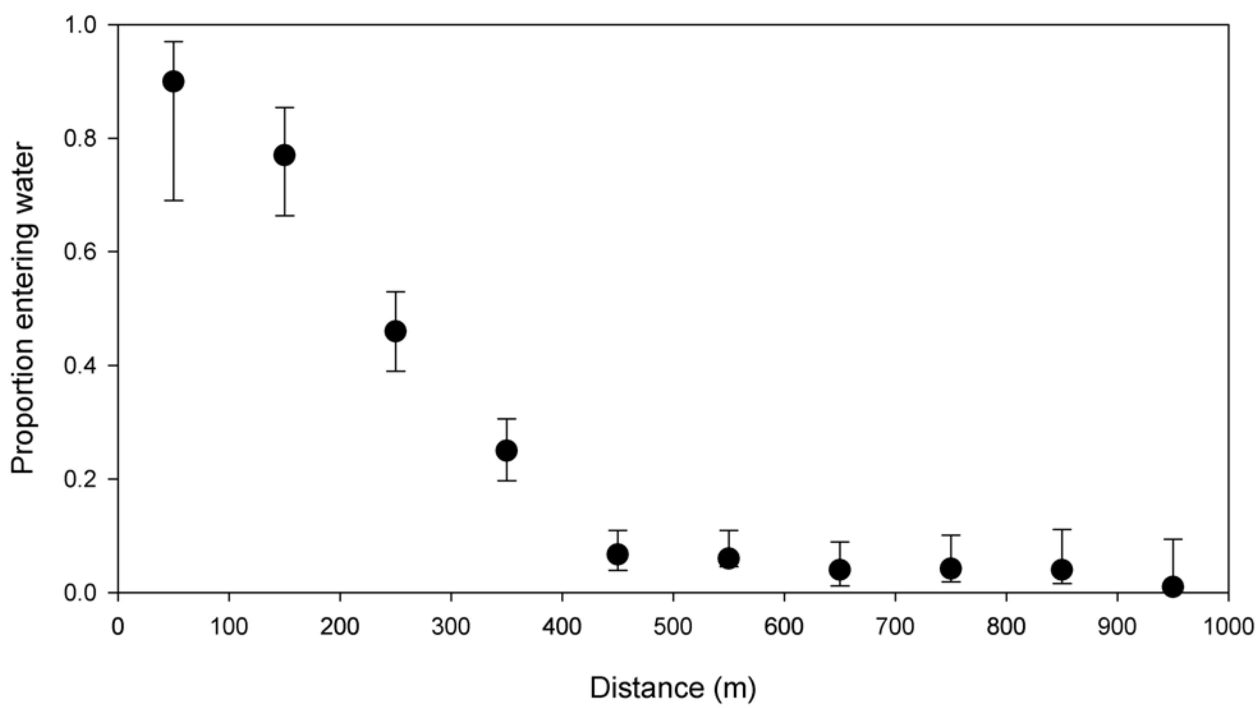

Figure 8. Estimates of the proportions of harbor seals entering the water in response to varying approach distances (in 100 m bins) by cruise ships in Disenchantment Bay, Alaska. Approximate 95% confidence limits (Agresti and Coull 1998) are shown. Note that a given proportion represents only the fraction of seals that entered the water (of those observed) within the relevant distance bin, i.e., a proportion does not represent the number of seals that have accumulated from bins of greater approach distances. The 100 m bins are represented at the midpoint (i.e., the symbol for the 100-200 m bin is plotted at 150 m).

the results of the Cox regression for distance (Fig. 5). In general, there appeared to be little water-entry response by seals to vessels at distances greater than about 500 m, but there was a strong increase in the probability that a seal would enter the water when approached at distances of less than 400 m. That the absolute response by seals appeared to occur at smaller distances than the relative response may be a reflection of the smoothing parameter used in the Cox regression, as well as a reflection of the aforementioned limitations for approximating absolute risks.

Because the estimated proportions of harbor seals entering the water when approached within 100-200 m neared 0.75 (Fig. 8), we conclude that a clear majority of seals approached by vessels at 200 m or less were sufficiently disturbed to enter the water.

Medium and Large Scale - aerial surveys

Analyses are underway to summarize the spatial distribution and relative abundance of seals in relation to variation in ship traffic during the season. Video and audio data from the tapes recorded during each medium-scale aerial survey are currently being translated into a GIS database. All the video tapes have been viewed and the data transcribed into raw formats (yielding 8938 distinct observations of seal groups and/or ice concentration). Some additional processing is required to prepare a database that will allow exporting into geographical analysis software (e.g., ARCGIS and S-PLUS).

Photographic negatives from the large-format photographic surveys have been scanned at very high resolutions (1600 d.p.i.), and harbor seals in the resulting digital images are currently being counted using image-processing software. Analyses of the 1267 images from Disenchantment and Icy Bays are expected to be completed in early 2004.

DISCUSSION

The preliminary analyses of the fine-scale studies presented here indicate that harbor seals in Disenchantment Bay respond to the presence of cruise ships. Harbor seals altered their normal behavior in the immediate presence of ships by vacating ice floes with increasing frequency at approach distances less than 500 m (± 100 m). Mothers and pups showed no differences in the distance or bearing to vessels at which they were disturbed compared to other seals. We intend that the data collected in 2002 will support much more extensive exploration of the suite of covariates that may influence the potential responses of seals to vessels, including weather conditions and recent patterns of vessel traffic in Disenchantment Bay. Inclusion of these other covariates may alter slightly the values or functional form of the covariates analyzed in this report. The qualitative form and the general magnitude of the influence of approach distance, however, are likely to be robust features that will not change significantly under refinements to the analysis. At the medium and large scales, we expect that the abundance and spatial analyses planned for the aerial survey data will address what proportion of the population is likely to be disturbed by ships and whether or not these seals (both within and outside the ship traffic corridor) respond by hauling out less often or by altering their distribution.

The results presented here are consistent with Calambokidis et al. (unpub. ms.) who found that an increasing proportion of harbor seals in Glacier Bay vacated ice floes with decreasing distance to cruise ships under 500 m. On average, more than 50% of the seals entered the water at distances to ships of less than about 300 m, surpassing 90% disturbance at less than 100 m – similar to our estimates. Speed of cruise ships and weather showed no obvious effect, though seals appeared to respond to ships at greater distances on clear, sunny days. Streveler (1979), reporting on 8 years of summer field seasons in Glacier Bay National Park, was the first to document human disturbance of harbor seals inhabiting tidewater glacial fjords. He focused attention on the potential for disturbance to cause separation between mother seals and their dependent pups, which has been shown to be a significant source of pup mortality at terrestrial sites, whether natural or human-induced (Johnson 1977). In Disenchantment Bay, though we observed mothers and pups responding to vessels – showing they had similar rates of water-entry relative to other animals – the extended observations necessary to suggest immediate impacts to pup survival were not possible from a moving platform. Still, a general behavioral pattern was noted by observers (similar to Calambokidis et al., unpub. ms.): the mother and pup would enter the water usually within a minute of each other – or if the pup was hesitant, the mother would maintain visual contact until the pup entered some minutes later – and the observation would end as the pair became obscured among the floating ice (and the observer focused on finding another group). We did not observe the sudden "crash dives" and lack of mother-pup coordination observed by Streveler (1979) in response to close approaches (<150 m) by small boats or extremely low-flying (< 61 m) aircraft.

These previous findings and those presented here indicate that cruise ships disturb the immediate behavior of individual seals (or groups), but evaluating the impacts of such disturbance on individual fitness – and ultimately population vital rates – is more difficult. If seals are compelled to spend more time in the water, then it is important to attempt to understand the possible consequences. Pinnipeds begin life on land or ice and subsequently haul out on these substrates. Though all species of pinniped haul out, some do so only to reproduce and molt whereas others, such as harbor seals, haul out throughout the year. The propensity to haul out differs relative to environmental conditions (e.g., solar angle and tide height) and across populations (Boveng et al. 2003). For example, harbor seals at terrestrial sites appear to respond primarily to tidal and diel light cycles (Watts 1996), whereas those on floating ice may respond mostly to the latter. Harbor seals in Alaskan glacial fjords exhibit a distinct diel rhythm with peak numbers on ice floes at solar noon (Glacier Bay, Calambokidis et al. 1987) or in the early afternoon (Aialik Bay, Hoover 1983; Tracy Arm, Jansen et al. 2001). At Tracy Arm, prior to the tour boat/ship season, radio-tagging studies estimated that 90% of seals haul out at some point daily, with an average 50-70% hauling out for some period between 10:00h-17:00h (Jansen et al. 2001). At Glacier Bay, visual counts suggest that 70-90% of seals haul out daily over the same period (Calambokidis et al. 1987). Such diel patterns, with number of hauled out seals peaking by day and diminishing by night, have been described widely and have been attributed to nocturnal foraging (see Watts 1996). Though night-time feeding is supported by studies examining directly the foraging behavior of Alaskan harbor seals (Frost et al. 2001), as Watts (1996) states: "this begs the basic question of why seals should [haul out] when they are not foraging".

The reasons seals spend time out of the water are poorly understood but two theories predominate: 1) immersion in water is energetically costly; and 2) the threat of being eaten by a submarine predator is significant (Watts 1996). It has been suggested that harbor seals are thermally neutral when active in the water (reviewed in Watts 1996). During periods of inactivity, however – as during periods of required rest or sleep – there is likely an energetic cost to staying warm if seals are compelled to remain in the water and do not haul out (Watts et al. 1992).

The threat of predation to harbor seals has not been rigorously examined, though predation on pinnipeds by killer whales (*Orcinus orca*) and sharks is well documented (reviewed in Jefferson et al. 1991 and Watts 1996 ; Lucas and Stobo 2000). Calambokidis et al. (1987) reported numerous kills and attempts on harbor seals by killer whales near terrestrial haul-outs in Glacier Bay, and observed them traveling frequently in central and lower parts of the bay. Interestingly, they did not observe any killer whales in ice-filled, seal haulout areas despite seven months of continued presence (i.e., observation camps) over three summers. Similarly, Streveler (1979) indicated that "killer whales have never been reported in Muir or Johns Hopkins' icepacks" in his experience in Glacier Bay over eight years. Moreover, even though cetaceans (i.e., harbor porpoise and beluga) were observed on numerous occasions during the extensive surveys flown for this study, killer whales were not among them. But killer whales in glacial fjords have been observed moving through loose brash ice, albeit infrequently. In upper Glacier Bay, two pods (8 and 22 animals) were observed during nine, daylong vessel surveys (1991-1993); the larger pod was a resident group which is believed to feed exclusively on squid and fish (M. Dahlheim, NMML, pers. comm); in Aialik Bay, only one pod (two animals) was observed in three weeks (D. Withrow, NMML, pers. comm.). Similarly, killer whales were seen in outer Yakutat Bay among dispersed ice floes on which several harbor seals were resting (B. Adams Sr., YTT, pers. comm.). Still, the notable absence of accounts of killer whales in *densely-packed* ice where seals occur in highest concentrations supports the view that such seals benefit from a lower risk of predation. The Inuit have long known that Arctic seals (and narwhals, *Monodon monoceros*) will enter scattered to dense pack ice when pursued by killer whales (Campbell et al. 1988).

The incidence of seals vacating ice floes clearly diminishes with ship distance out to at least 400 m, perhaps as far as 600 m. At greater distances, the effect of cruise ship approaches starts to level off suggesting that the frequency of seals entering the water at those distances is nearing ambient levels (i.e., levels expected in seals behaving naturally). However, concomitant with the seeming diminution of responses at greater distances is a sizable increase in the error margins (i.e., 95% C. I.). This result is an unavoidable consequence of smaller samples resulting from the decreasing detectability of seals with increasing distance from ships. Still, if the inference is correct that the most overt response to ships (i.e., seals entering the water) reaches zero at about 500 m, it is logical to predict that harbor seals may respond in other ways (e.g., increased alertness or agitation) at greater distances since these less overt behaviors are usually precursors to entering the water. Analyses of the frequency of these other behaviors (measured in this study) relative to approach distance by ships is ongoing.

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Appendix 1. Harbor seal behavioral observation guidelines: Disenchantment Bay, 2002.

(Instructions to observers on cruise ships for how to collect data for this study)

1. Selecting an observation post: Each observer should perform their observations in one of the four quarters of the ship (i.e., some combination of port, starboard, bow, stern). For example, if you select the port bow post, observe seals from the time that you can first view them well until they pass abeam of the ship. If you select the starboard stern, you would begin your observations as the seals come aft of the ship's beam, continuing your observations until you can no longer see the seals well.

2. Selecting seal groups: At the beginning of the in-ice observation period, select a group of seals hauled out on ice. A "group" can be one or more seals on a single ice floe. Assign that group an ID number, from 1 through whatever number of groups you, as an individual, observe that day on that ship. Remember to include both small and large groups in your sample. Also include groups that are both close and far from the ship's track. Number groups sequentially per ship visit (event), starting with 1. Use an observation position prefix for port bow (PB) port stern (PS), starboard bow (SB), and starboard stern (SS). Example: PB-1, PB-2, PB-3, etc.

3. Mothers and pups: Whenever possible, select seal groups for observation that include mothers and pups. Don't assume that all small seals are pups; yearlings can be nearly the same size as pups. Pups can be identified by their bright, shiny, fresh pelage (yearlings have duller pelage, which they will be molting in the coming weeks) and by close physical proximity to adult females.

4. Observation sampling: This study's experimental design calls for continuous monitoring, with independent observations of a seal group (or individual) being allotted into 15 seconds intervals, separated only by the amount of time necessary to record the data. Use a countdown timer to start and end the 15 second observation period. When the group passes out of your observation area (ship's quarter), select another group when it becomes available.

5. Recording observations: For each 15 second observation period, record the group ID number, the start time of the observation, and the group size (note that this may have changed since the last observation if seals entered the water). Record the number of seals that showed each level of excitement during the period. Score only the "highest" level of excitement for each seal during that period (head up is the least excited, entering the water is the most excited). For example, a seal that was resting at the beginning of a 15 second period, but then raised its head, moved across the ice, and then entered the water during that 15 seconds would be scored as "enter water." Record counts for mother's, pups, and other seals separately.

6. Distance and bearing: Estimate distance using the range-finding binoculars or inclinometer (record degrees of inclination for the latter). Also record the approximate relative bearing to the ship's course in 15° increments. For example, straight off the bow would be 0 or 360, the port beam is 270, aft is 180, the "2 o'clock" position is 60, and the "7:30" position is 225.

7. Other covariates: For each seal group observed, enter estimates of ice coverage (in 10ths within a 50 m radius of group) and ice floe size (longest axis). Note weather conditions at the beginning of observations and then as significant changes occur. Note the incidence of other potential sources of disturbance (e.g., ships, boats) at the time they are first observed.

Appendix 2. Observation form: Event information and weather and vessel data (Disenchantment Bay, 2002).

Event number: ________(page ___ of ___)
(assign each ship its own event number)

Harbor seal observation form

Date:___________2002

Vessel:________________ Captain:________________ Observer for data recorded here:__________________ Obs.height(m):______

Other observers participating in this event:____

Embark ship time:______Disembark ship time:______ In-ice observation periods – inbound:______-______outbound:______-______

Weather conditions during in-ice observations (record every 30 minutes and whenever precipitation changes)

Time (hhmm)	Visibility (km) (check one box)						Cloud cover (check one box)				Precipitation (check one box)				Wind speed (knots) (check one box)								Wind dir (bearing relative to ship)	Temp (°C)
	<0.2	<0.5	<1	<5	<10	>10	Clear	Partly cloudy	Low overcast	High overcast	None	Fog/drizzle	Light rain	Heavy rain	0	<5	<10	<20	<30	<40	<50	>50		

Vessel traffic during entire time aboard cruise ship (as feasible, record every boat, ship, or aircraft observed)

Time	Vessel type and length	Location relative to cruise ship	Describe vessel's course and approximate speed

Appendix 3. Observation form: Seal behavioral observations (Disenchantment Bay, 2002).

Event number: ________(page ___ of ___)

Seal behavioral observations OBSERVER______________, POST (check 1): bow___ stern___

(observe groups of seals for consecutive 15 second intervals until they pass abeam of the shipor enter the water) (check 1): port___ starboard___

Group ID (number sequentially, for example: PB-1, PB-2, PB-3, etc.)	Time (HH:MM)	Group size (number of seals)			Mother behavior (number of seals showing "highest" excitement level observed)				Pup behavior (number of seals showing "highest" excitement level observed)				Other seals (number of seals showing "highest" excitement level observed)				Location relative to ship		Ice	
		Mothers	Pups	Other seals	Resting	Head up	Move across ice	Enter water	Resting	Head up	Move across ice	Enter water	Resting	Head up	Move across ice	Enter water	Est'd distance (m or deg)	Relative bearing (15°/30 min incremnts)	Floe size (m, ongest axis)	Ice cover (10ths, w/i 50 m, est'd abeam of ship)